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THE ROMANCE OF WATER STORAGE[1]

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Thirty short years ago this country was the victim of gross ignorance respecting the disease-producing potentialities of public water supplies. Typhoid fever was rampant, and in a single decade millions of persons grievously suffered and hundreds of thousands died in consequence of disease brought to them by the unostentatious agency of impure water. Incidentally, in this ten-year period there passed beyond all recovery the stupendous sum total of $2,625,000,000 in vital capital due to typhoid fever alone.

In the space of this single decade one in every 35 persons in the United States contracted typhoid fever, but the lay public saw nothing particularly alarming in that, reasoning that about so many people every so often were destined to enter the realm of darkness by reason of various and sundry disorders, of which "bowel trouble" was one. But a few men, more given to serious thinking than their fellows, and more skilled in the arts and sciences, took counsel among themselves and decided that the existing state of affairs was entirely unseemly. It was pointed out that in our twenty biggest cities alone 36,000 souls were being hurried toward eternity each year because of typhoid fever, and in that space quite one-tenth of these actually arrived at "the undiscovered country from whose bourn

[1] Read at the Cleveland Convention, June 8, 1921. Further discussion is desired and should be sent to the Editor.

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no traveller returns." It was hinted that the vast bulk of this annual human expedition might have received its tickets from polluted water supplies. The question was, what should be done to stop this involuntary permutation of human life into the intangible essence of ethereal similitude?

Sundry remedies were suggested.[3] In the opinion of some all water used for drinking should be boiled; in that of others that it should be distilled; still others held that it should be treated in domestic filters; while another group advocated the filtration of all water used for the public supply of all needs.

Still another faction submitted that initial prevention was the infallible cure for this desperate state of affairs; that quite the only thing to do was definitely to stop the pollution of all public waters. A branch of this element not only was disposed to prevent all initial pollution, but for fear somebody might slip in a few disease germs while the watch was asleep desired that the water should be allowed to impound in large reservoirs before use, that such incidental living contamination as might get by the prevention squad would thus be afforded time to repine and die of old age and discouragement through unrequited ambition.

Suffice it to say that of the 22,800,000 people supplied in 1890 from 1,878 public water works, less than 1.5 per cent were furnished filtered water. The cholera epidemic in Hamburg had not yet occured to teach its striking lesson. The classic investigations at the Lawrence Experiment Station had only just gotten well under way. Frankland's invaluable studies on the removal of bacteria by water filters had not yet been developed on a decisive scale, and the scientific mind was still groping about in the dark for the push button which would force the illumination of the abysmal darkness surrounding the proposition of how to make impure water pure. The only thing clearly recognized was the precept as old as the ages, namely, that the Mosaic Law had merit.

In the decade 1890–1900 things began to happen. Frankland was on the eve of proving that filters remove bacteria from water. The Hamburg epidemic proved that filtration of grossly polluted water would eliminate the disease germs it contained. The studies at Lawrence, Providence, Louisville, Pittsburgh and Cincinnati taught the craft how to purify water by practical means. About

[3] See also Proceedings of the Eighth International Congress of Hygiene and Demography, Buda-Pest, September, 1894.

1,500,000 more people were added to the total of those whose public water supplies were filtered, raising the grand total in 1900 to about 2.4 per cent of the total population of the United States. The main accomplishment, however, was the development of precise knowledge of the menace in impure water and practical methods of correction.

The decade 1900–1910 was an era of accomplishment. Based upon the knowledge acquired in the previous decade, water filter plants were built in scores of cities, and the filtered water population increased from the 2.4 per cent of the previous decade to nearly 12 per cent. One in every four persons representing the urban population of the United States was being supplied with filtered water in 1910. Moreover, in the ten years ending 1910, the typhoid fever death rate in the registration cities of the United States fell from 36 to 22 per 100,000 population living. The good work has continued through the decade just ended. Some 25,000,000 people are now supplied with filtered water, and the typhoid fever death rate in the registration cities has fallen to an average of 10 per 100,000 population living.

Strange to say, however, at this late and more enlightened day there exists an element among public sanitarians the leaders of which still cling to the idea that it is permissible to rely upon primary lines of defense against water-borne disease, such as depopulation and sanitary patrol of watersheds and storage of surface waters in impounding reservoirs. This element is not insensible to the additional and complete protection afforded by artificial processes of water purification, but for assumed reasons which are utterly beyond the ken of the author they offer vague arguments against water filtration and sterilization "except where necessary."

The filtration or sterilization of all surface water supplies is always advisable and in the strictest sense is always necessary. Certainly the cost attendant upon the utilization of such definite lines of defense against water-borne disease is justifiable because of the assurance of water purity they afford. Minimization of initial pollution is splendid water supply sanitation; storage is a link, however weak, in the preventive chain; but filtration and sterilization give the finishing touch, and with or without the aid of the primary measures of prevention just referred to they afford the protection against water-borne disease to which every American citizen is entitled. The dice of God are always loaded, and it is just as well

to be prepared for the worst. This aphorism applies equally well to water supply practice and all other lines of human endeavor.

So much for a brief résumé of the subject of water supply sanitation. The muttons of our repast have not yet been set upon the table, nor particularly mentioned except in the bill of fare, so to speak. To these we now come with the full expectation of serving them with a sometime vinegary sauce of truth; and it is hoped that the author may be pardoned for stating truths in a paper which he has frankly labelled "The Romance of Water Storage."

The impossibility of preventing absolutely the dangerous pollution of surface waters. There are certain standard methods which, individually or combined, usually are followed in attempts to preserve the pristine hygienic purity of surface water supplies, namely, acquirement by purchase of the watershed, diversion of isolated and community sewage from the streams draining the watershed, community sewage purification where diversion is neither feasible nor possible, and intense watershed patrol. The author wishes to place himself on record emphatically as favoring any and all reasonable attempts to head off at the source dangerous pollution of surface waters. Unfortunately, however, there is a marked tendency in some localities to place too great reliance on this form of water-borne disease prevention. It is all right so far as it goes, but it is not the Q. E. D. of the problem of satisfactory public water supply by a long shot.

Under normal circumstances the acquirement by purchase of the entire catchment area is too expensive an undertaking to be considered for more than a brief moment. Furthermore, a catchment area being purchased in its entirety, the circumscribed landscape profusely dotted with "No Trespass" notices, and the often more or less somnolent patrol given the charge of enforcing the no-trespass rule, does not and cannot afford adequate assurance that the waters flowing from that area, uninhabited except by the patrol or chance trespassers, will not at some time become the vehicle of disease germs, grievously to upset the calculations of the fathers of the primary prevention idea, and the inner mechanisms of the innocent ultimate consumers of these waters if furnished to them without purification.

A large proportion of Americans are imbued with the idea that democracy, liberty, freedom and the rest of our high flung but more or less fanciful shibboleths spell license and authority to do as they

please. This idea, initiated by Eve who partook of the forbidden fruit under the urgency of his Gehennic majesty that she assert her independence, is developed to a far greater degree in the American that in any other nationality. The German obeys the ubiquitous "Verboten" of his country because he has been taught to respect his national laws; the Englishman follows the set lines of procedure in his country because the other thing "isn't done;" but the American will travel far to circumvent the law in order to show his independence of authority and his ingrained repugnance of organized efforts to curb his natural impulses. In this connection witness the lengths to which the average American will go, the chances he will take and the money he willingly squanders in order to beat the Volstead Act. Men who never took a drink in their lives before the passage of this law now are competent authorities on home brew.

Take a watershed and remove all habitations from it, place a sanitary patrol on the job to prevent the deposition of human excrementitious matter; and if there are birds or rabbits in the woods, or fish in the brooks thereon, or wild berries or flowers for the picking, that patrol must be a mighty energetic and conscience driven body, individually as well as collectively, to stop at the indefinite confines of the watershed the rabbit hunter, the fisherman, the berry picker and the nature-loving flower gatherer. Then, too, patrolling a watershed is a lonesome job akin to sheep herding, and a little pleasant time-consuming intercourse with potential trespassers is not always rejected by the stern dictates of duty.

The public *will* enter upon the sacred confines of a watershed whose soil is dedicated by its purchasers to an eternity of hoped for immaculateness. Such trespassers may be uninvited, and perhaps unwitting, violaters of these hallowed premises, but anybody who has ever viewed a "Battle Royal" knows how difficult it is for a participant to keep an eye on the other contestants every one of whom is imbued with an all-embracing desire to hand him the lethal punch. Similarly, while passing the time of day or administering a reproof to one trespasser two more at another point may enter upon the ground a patrolman is guarding.

Any one of these, even the patrolman himself, may be an unsuspecting carrier of disease germs. When Nature calls, and her message is of a certain character, we all obey that call without unnecessary delay. If we are supporting an incipient case of typhoid fever we respond with even greater celerity than when we are not.

The nearest cover is promptly sought, and the urge of Nature satisfied. Thereafter a little shower of rain, a short aqueous travel from the clump of bushes to the nearest stream, and Mr. and Mrs. Bacillus Typhosus and the children have carried the movement to a point where, without the inhibiting activities of sedimentation, filtration and sterilization, the consumer of the water from this patrolled and supposedly immaculate watershed, soon will have a "little movement with a meaning all its own."

What water storage will do. Where it is feasible on engineering and financial grounds to impound surface water supplies in natural ponds, lakes or artificial reservoirs, there is no question about the advisability of availing of this line of defense between the gathering ground and the ultimate consumer. The trouble is that too great and unwarranted confidence has been placed in water storage competently, uninterruptedly, and consistently to remove the menace from such disease germs as may find their way into storage reservoirs.

The value of storage in the correction of the physical and hygienic imperfections of surface waters is very largely measured by the period of that storage; that is, the time elapsing between the entrance and exit of the water in the reservoir. Factors which upset a definite measure of the benefits of water storage are stratification and various currents, temperature changes, and wind action. A reservoir may have a theoretical displacement period of 100 days, and be considered in consequence a pretty fair purifying medium; but short-circuiting of the flow through the reservoir may actually cut the theoretical period of storage to a very few days, or even hours, and by the same token this identical reservoir of which so much is theoretically to be expected may then prove to be a delusion and a snare. Particularly is this condition aggravated when most of the reservoir surface is frozen over and the discharges from the entering streams follow a quite direct line from their points of entrance to the outlet of the reservoir. Temperature changes in the spring and autumn of the year, bringing about the periodic "overturns" which produce complete vertical mixing of the waters of the reservoir, upset all theoretical calculations. Strong winds toward the reservoir outlet tend to carry swiftly thereto the entering waters of the streams which feed it.

Water storage, in the concrete, will reduce the physical imperfections of a water through sedimentation, in extent depending

directly upon the degree of quiescence, the period of storage, and the hydraulic subsiding values of the particles of suspended matter the water initially contains. It will reduce somewhat the color of water due to vegetable stain through the bleaching action of the sun, but the sun is off duty for more than half the time, and even when patrolling its beat its bleaching action is manifested only at or relatively near the surface. Finally, and what is by far the most important, storage of water will reduce the numbers of disease bacteria to a marked degree through the agencies of unfavorable environment, sedimentation, insufficient and unsuited bacterial food supply and the inimical activities of predatory protoza.

What water storage will not do. Storage of surface water in natural lakes and artificial reservoirs produces a beneficial effect upon its physical and hygienic qualities as an average proposition, but its action is not thorough, nor is it consistently reliable. If polluted water enters a reservoir the chances are a hundred to one that sometime, under the primary influence of freshets, short-circuited flows, seasonal overturns or what not, that pollution, in part at least, will find its way to the outlet of the reservoir. The pollution entering the reservoir need not be continuous or large in volume. Indeed, the evidence is striking on the point that the disease-germ infected excrement of only one or two persons is sufficient to contaminate with disastrous results surprisingly large volumes of water. The experiences at Plymouth, Pa., New Haven, Conn., York, Pa., and Scranton, Pa., furnish incontrovertible evidence on this point.

Regardless of all the legislative action in the world, and all the efforts on the part of patrolmen hired to prevent such things, people will fish and even bathe in waters impounded for public supply. There may be only a few who will display such indifference to the law but they exist nevertheless. Again, it has not been found impossible for favored ones with the necessary "pull" to obtain limited permits to fish in such waters. These people have only to be suffering from typhoid fever at the time to make almost inevitable the pollution by them of the waters in which they are fishing. One person can discharge in one evacuation of urine enough typhoid germs to place one or more of these germs in every glassful of a 5,000,000,000-gallon reservoir. Fishing or boating in impounded waters used for public supply without subsequent purification should never be permitted. Even the issuance of limited permits in special cases is a dangerous practice, for once out on the face of such waters

in a boat, and with the conveniences of the land a considerable distance away, the use of the water as a point of deposition of dejecta is almost inevitable, and there is no assurance that the person to whom a permit of this character is granted is not unknowingly suffering from incipient typhoid, or a typhoid carrier.[4]

In fine, while the storage of surface waters in large lakes or reservoirs has a decided beneficial effect on the quality of the water as an average proposition, it cannot be depended upon as a consistently reliable performer in the field of water purification. The benefits of storage are here today and gone tomorrow because of factors in themselves beyond the power of man to control. Where a community desires a water supply as safe as the natural conditions and the inventiveness of man can make it, and that water is derived from surface sources, something more is needed than the acquirement of the catchment area by purchase, its subsequent unremitting patrol, and the storage of the runoff for days, weeks, or months. Too many physical, thermal and human vagaries enter into the problem to make it permissible for the sanitarian to stop at this point. The procedure outlined may solve the conundrum for 364 days and 23 hours of the year, but in that one remaining hour all precedents, good intentions and convictions may be blasted from their inherently insecure foundations, and a disastrous epidemic of water-borne disease cast its pall of death upon a misguided community relying on part way means of prevention.

There is no sense at all in persistently residing in a fool's paradise. All surface waters, be they derived from perpetually snow-capped mountain regions or from acquired, untenanted and patrolled areas, are potentially dangerous in that they are open to incidental, accidental, or deliberate pollution. Storage of such waters cannot be relied upon to make them continuously safe for human consumption. To presume that storage can be so relied upon is to ignore the epidemics arising from polluted impounded water supplies, and which are a matter of undeniable record. Such a position is untenable; is unnecessary because of the existing knowledge of how to make public water supplies entirely and continuously

[4] A noteworthy addition to the literature on this phase of water storage was contributed last summer by X. H. Goodnough, director and chief engineer of the Department of Engineering, Massachusetts State Board of Health. It can be read with decided profit by those interested in the subject. See *Journal* New England Water Works Association, September, 1920, page 151.

safe by methods subsidiary to storage; is fanciful because those whose mentalities convince them that it can be done for the reason that no disaster has yet attended their own practice in that primary line of disease prevention alone, have not had their personal lesson; and romantic altogether in face of the facts. There is as much sense in such a position as there is in the report that "Mr. Jones fell from the second story of his home and broke his neck. Otherwise he was entirely uninjured."

Conclusions. The endeavor has been made to prove that the problem of making surface waters safe for public consumption involves the application of a chain of preventive measures constituting in effect four major lines of defense against water-borne disease, namely:

(*a*) Maintain the catchment area in as sanitary a condition as practicable; that is, guard against gross pollution entering the streams and lakes which drain the watershed.

(*b*) Store the water in natural lakes or artificial reservoirs, provided such storage is available or dictated by sound engineering principles.

(*c*) Coagulate and filter.

(*d*) Sterilize.

There will be some variations in the application of these measures. The first (*a*), stands always unchanged as an elemental requirement of common sense and decency.

In the case of the second (*b*), where natural facilities for storage are already at hand they will of course always be made use of. Where they are not, and the construction of a dam to form a reservoir is required, aside from the purely engineering aspects of this phase the only consideration which need be debated is whether or not the burden on the ultimate filter plant will be substantially lessened by pre-storage for a long period. If the raw water is grossly polluted or heavily charged with mud, silt or clay such storage is sometimes highly advantageous.

In the third case (*c*), there may be instances where coagulation is unnecessary and where cost and other factors, including local public sentiment, indicate slow sand filters. Only where coagulation is unnecessary, and where climatic conditions and the chemical composition of the raw water are favorable to such treatment, should slow sand filters be considered. The author prefers the rapid sand filter in any and all cases. It is less easily upset by climatic changes, and in competent hands is susceptible of less likeli-

hood of "going wrong," and of more ready readjustment if it should, than is the old-fashioned slow sand filter.

Respecting sterilization (*d*), this should never be omitted from the list of preventive measures. It is not a 100 per cent safeguard when used alone except in those very rare cases where the raw water is all of the time, without any exception, free from suspended matter. In all cases the practice should be maintained of applying the sterilizing agent continuously, never periodically. To sterilize only when it "seems to be necessary" is as pernicious a practice as temporarily suspending the operation of a filter plant or the use of a coagulant when the water looks all right.

In by far the great majority of relatively large communities the problem of protecting the public from water-borne disease should embrace the application of watershed pollution minimization, and purification by sedimentation, coagulation, filtration, and sterilization. Any community using surface water would do mighty well to set up for continuous maintenance all of these lines of defense. To rely solely on the primary line of prevention, watershed patrol and water storage, is to invite inevitable disaster. Disease germs never send a herald in advance to proclaim their coming, and it is true water works and general civic economy always to be thoroughly prepared for their complete and satisfactory reception. Then, but not otherwise, the ultimate water consumer may drink, not only with his eyes, but freely, satisfyingly, and without hazard of his life.

DISCUSSION

J. W. ELLMS:[5] In this paper the author has pointed out the potential danger in depending alone upon the storage of public water supplies derived from surface sources for the elimination of pollution. He shows the weakness of the ordinary preventive measures employed, and the absolute need for the dependable processes of filtration and sterilization. With the author's point of view the writer is in entire accord.

Probably there is nothing more difficult to change than human opinions, and especially where such opinions are based upon custom and practice, and where there is possibly an unconscious prejudice against the remedies suggested for effecting a change. Although the opposition to modern methods of water purification, especially

[5] Frazier-Ellms-Sheal Co., Consulting Engineers, Cleveland.

where chemical coagulating and sterilizing agents are employed, is by no means as pronounced or as open as formerly, nevertheless it still lingers in the mind of the layman more often than is usually suspected; it is even latent in many sanitarians, who will resort consciously or unconsciously to such measures as storage of surface waters or methods of filtration known to be inadequate for the problem in hand. The impounding of surface waters has its place from a sanitary standpoint in every system of water supply where it can be used; but for reliance to be placed upon it as a sole or even principal measure of purification is futile and dangerous, and becomes more so as the population on watersheds increases.

Sanitary engineers have made remarkable inroads upon the devastation wrought by typhoid fever in the United States by cleaning up its water supplies. However, much remains to be done, and much may still be done by recognizing the inadequacy of so-called "natural methods of water purification," and by insisting upon utilizing and perfecting the well known and thoroughly proven methods of purification now available. Infant mortality and morbidity must still be reckoned with, even though the typhoid fever death rate may be low, for there is a well grounded suspicion amongst physicians that impure or poorly purified water supplies are frequently responsible for the sickness and early death of many children.

Engineers are much indebted to Colonel Johnson for his persistent efforts in showing the dangers of water-borne diseases, which he so well described in his previous paper on the "Typhoid Toll," and which he has most admirably supplemented by the paper under discussion.

THEODORE HORTON:[6] Whether the subject is viewed as romance or tragedy, the writer feels substantially in accord with the facts, views and conclusions of this paper. He also is quite in sympathy with the intolerance expressed by the author toward that group of altruists, or theorists or reactionists, whatever you may be pleased to call them, who find it difficult to distinguish between principles and practice, to readjust their views in the light of changing experience, and to realize what is meant by safety when applied to public health and human life.

Fortunately the work of State Departments of Health which have established engineering divisions whose activities extend to

[6] Chief Engineer, New York State Department of Health, Albany.

supervision of public water supplies, affords fruitful opportunities to observe, on ample numerical scale, the effects which various and changing conditions of arrangements and operations of water works have upon the public health of communities. These variations cover a wide range of conditions respecting character and intensities of pollution on the one hand and natural and artificial means of removing it on the other hand. Particularly is this so in regard to facilities for determining those factors as furnished by laboratory tests, sanitary survey and epidemiological data.

With some 550 public water supplies in New York State, all of which have been fully investigated, and many repeatedly reinvestigated, by the Engineering Division of the State Department of Health, with such facilities as a Vital Statistics Division always at hand to furnish statistics as to incidence of typhoid fever and other water-borne diseases, with a Laboratory Division always available to make analyses as occasion requires, and with experience of numerous outbreaks in the past, the history of which has furnished epidemiological evidence of sources of infection, it has been possible to repeatedly compare both absolute and relative efficacies of various natural and artificial conditions and safeguards of many of these water supplies. These investigations and studies have now been carried on for some fifteen years, during which most of these supplies have been greatly improved in sanitary quality, some through improvement on the watershed, others by storage, still others by filtration or chlorination or both. To be more explicit, in 1906 there were approximately 400 public water supplies in the state, serving a population of about 6,000,000 persons. Of these supplies about 50, serving a population of 700,000, received some sort of treatment, either by slow sand or mechanical filtration. In 1919 there were approximately 530 public water supplies in the state, serving a population of approximately 8,5000,000. Of these supplies, about 130, serving a population of approximately 6,900,000, are treated either by filtration or chlorination. This means that in the thirteen years, from 1906 to 1919, the number of persons supplied with public water supplies had increased from 6,100,000 to 8,500,000, or approximately 40 per cent; while in the same period the number of persons protected by water purification in some form, had increased from 700,000 to 6,900,000, or an increase of almost 1000 per cent. During this period also the typhoid rate for the state which, prior to 1906, had averaged about 23, has been reduced from about 20 in 1906 to 3.0 in 1920.

During these years of struggle for better water supplies, which has resulted in almost an elimination of typhoid fever from the state, many lessons were learned of the efficacy and the limitations of the many natural and artificial measures in the protection of public water supplies. Among these lessons, as bearing especially upon the subject of the paper may be mentioned, first, that what might be termed "natural protection," or the exclusion of pollution from the water supplies and the watershed, while desirable in any case, is in no case a sufficient or satisfactory safeguard to any supply. It must, of course, be admitted that within reasonable limits of cost, and for aesthetic considerations, such precautionary measures are always desirable. As an only safeguard, however, it is entirely inadequate; and experience in New York State has fully demonstrated that not only are such supplies, only so protected, always subject to the imminent danger of incidental, accidental and wilful contamination, with its always possible infection, but that it is only through artificial and other more effective means of protection, accomplished through some sort of purification, be it no more than chlorination, can those supplies be effectively protected. Furthermore the writer is convinced that on sparsely inhabited, or even so-called uninhabited watersheds, a greater degree of security can be afforded by chlorination, notwithstanding its limitations, than by methods of patrol, for the same expenditure of money. Thus, to be even more explicit, the writer feels that the old traditional notion of relying upon sanitary patrol of a watershed to maintain a supply pure, in place of artificial protection, should, in the light of present knowledge, be reversed; that is, it will be safer to first chlorinate (or filter if that can be afforded) and then clean up the watershed and maintain it as clean as practicable (at least from direct sources of contamination), always keeping in mind that the so-called "uninhabited watershed" does not exist as a reality in these days when the hunter, fisherman, tramper, canoeist, picnicker, to say nothing of sea gulls and other scavengers, all contribute their share of contamination and possible infection.

Another lesson which experience has clearly and repeatedly demonstrated in this State is the one brought out by the author that storage of water in reservoirs, lakes and ponds can only be depended upon as a very crude barrier of defense. The writer does not mean to underestimate the great value of storage when the full effect is felt. This effect however, only rarely occurs, and while

the author has referred to thermal changes, overturn and wind currents, he has perhaps not emphasized as much as he might, the importance of this latter influence. The atmosphere is nearly always in motion, and few are the days during any year when this action, based upon the well established ratios of wind velocities to induced currents, will not produce currents sufficient to carry pollution a distance of 4 or 5 miles; and on many days 50 miles.

Many factors, of course, contribute to lessen the effect of contamination carried by surface currents in this fashion, such as sedimentation, dilution and sunlight, as mentioned by the author, and this may account for the traditional notions still held by some as to the great value of storage. When one considers, however, that there are comparatively few days in the year when the wind action will not carry surface pollution from nearby, and even distant shores, to water intakes; that these surface currents are likely to keep bacteria in a state of suspension; that these time intervals of travel are too short for sunlight to be very effective, there seems to be little left in the "storage theory," in the language of the author, but romance. In fact, New York State has furnished a number of epidemics due to infection conveyed by wind currents in lakes, and one of these during the present year. Furthermore, if one will study the analytical results of water supplies taken from lakes and reservoirs, even though subject to only slight pollution and with intakes favorable located, he will generally find that at intervals, usually irregular but occasionally seasonal, and depending upon position of polluting source and prevailing direction of winds, B. coli and other evidence of contamination will appear and that at other times the water may show no contamination whatever.

If safety means anything, it means safety at all times. It means protection not only from direct sources of pollution on an inhabited watershed, but from the hunter, fisherman, bather and others who may stray onto or even camp upon our so-called "uninhabited watershed." This protection may be fairly well afforded by such barriers as watershed patrol, warning signs, water storage, and properly located intakes; but if a supply is to be made safe against not only direct sources of pollution but also incidental, accidental, and wilful contamination derived from possible typhoid carriers roaming promiscuously over the watershed, or from the ofttimes referred to "harmless surface drainage from farm lands," any coli from which will be attributed to the cattle and not the human

beings who care for them, it will be necessary to resort to the more definite, positive and reliable means of protection which the now highly developed art of water purification has placed at our disposal.

H. W. CLARK:[7] It is a pleasure to comply with a request to discuss this paper, especially in view of Colonel Johnson's discussion of the writer's paper before the New England Water Works Association last September and the fact that the present paper appears to be a continuation of that discussion.

There is no doubt in the writer's mind that Colonel Johnson states a self-evident proposition, known to every water works engineer and expert, when he calls attention to the fact that depopulation and sanitary control of watersheds, storage of water in reservoirs, filtration and sterilization are all of great value in rendering surface water supplies safe to their consumers. He probably has no greater faith in filtration than the writer, who has had investigations on that subject under his direction for more than a quarter of a century, has directed and improved at various times the operation of a number of municipal filters, both slow sand and mechanical, in New England and elsewhere, and can with all due modesty say that he has planned and overseen the construction of a municipal filter or two here and there in this country. The various historic epidemics of typhoid caused by water, referred to by Colonel Johnson and quoted by Mr. Goodnough in his paper before the New England Water Works Association Convention in September, 1920, are also well-known to the writer. He would only call attention again to the facts, as he did on a former occasion, that in Massachusetts dependence on storage of surface water for safety is still largely relied upon, that comparatively few filters are in operation here and that, notwithstanding the State's culpability in this respect, according to Colonel Johnson, Massachusetts is believed to have the lowest typhoid death rate of any state in the country and no water-borne epidemic of this disease has disturbed it for many years. This does not mean that the State may not have such an epidemic or that the writer does not believe in filtration, but the probability of such epidemics from stored water unfiltered becomes less and less as typhoid dies out here, as it apparently is doing, and the number of cases of wandering typhoid patients diminishes as it undoubtedly has during the past few years.

[7] Chief Chemist, Department of Public Health of Massachusetts, Boston.

Colonel Johnson is apparently disturbed because a more active propaganda is not carried on here to urge or force the installation of filters and apparently wonders that the State Department of Health is able to sleep o'nights with so much unfiltered surface water coming into Massachusetts homes day after day. As a matter of fact, the Department has little or no mandatory power in this matter of filtration and it can hardly, considering the remarkable local freedom from typhoid, hang out the red flag of warning too conspicuously or in too large pattern because there was a typhoid epidemic due to polluted water in Plymouth, Pa., in 1885, or one in New Haven, Conn., in 1901. This is not said flippantly. Reason and common sense in health matters are as necessary as in other mortal affairs and the State has a large body of intelligent and capable water works officials, most of whom are conversant with the relation of water supplies to health.

The writer would conclude by saying again, as he has often said in the past, that personally he prefers a surface water filtered for cleanliness as well as for safety, and believes that cleanliness should be dwelt upon more than it generally is by water works engineers, but nevertheless the facts in regard to storage, filtration and typhoid in Massachusetts are as stated in his paper before the New England Water Works Association Convention in September, 1920, and as he has briefly summarized them here.

E. E. LOCHRIDGE:[8] Colonel Johnson has outlined the case for the careful purification of water very fully. As time goes on the users of city water are becoming more exacting in their demands. They insist that the water should have not only the purity which was somewhat rare a few years ago, but also pleasing appearance and taste. It is safe to say that no municipality which has ever been furnished a nice appearing water in which there was the utmost confidence of its purity, is ever willing to accept a water that is in any way less desirable.

While wonderful results have been obtained by storage, by careful control of watersheds, and by other means which tend to make a natural water safe, there is, nevertheless, a constantly growing demand for a purification which would make the quality of the water uniform at all times.

[8] Engineer, Water Department, Springfield, Mass.

In his conclusions Colonel Johnson advises the maintenance of the catchment area in as sanitary a condition as practical as a minor requirement; depending upon the storage, coagulation, filtration, and sterilization to complete the work. The only exception which could be taken to this, it would seem, would be that in cases where it is practicable, the prevention of pollution should be as systematic as possible, in order that there may be every possible guarantee of a pure water from the start. This, of course, is not always possible; and, as the author points out, the chance pollution is a certainty at some time or other, to avoid which later processes should be maintained.

There will probably be a general acceptance of the conclusions drawn; not only from the standpoint of sanitation, but also for the general quality and appearance of the water.

W. H. DITTOE:[9] Colonel Johnson has quite frankly bared the facts concerning water supply protection and purification, and all who are unprejudiced must be convinced of the truth of his statements.

As its name implies, "water purification" is the process by means of which impure water is rendered pure. The process is not fully successful unless the final product is absolutely and continuously pure. No process of purification can be fully successful, therefore, if it is called upon to perform more work than it can reasonably be expected to accomplish from day to day and under all conditions. We must recognize the limitations of the various agencies of water purification and must employ these agencies with generous safety factors in order to insure a continuously pure product.

Protection and maintenance of watersheds, storage of water, coagulation and filtration, and disinfection have their respective limitations in converting impure water to pure water and these limitations must not be overlooked. There is a real need for a set of working standards to define the permissible and reasonable burdens which should be placed upon water purification processes. Likewise, uniform standards of quality of the product of the principal features of the process should be established. For instance, in the case of a rapid sand filter plant, standards of quality (bacteriological and physical) should be established as follows: First, of the water

[9] Chief Engineer, State Department of Health of Ohio, Columbus.

passing from the coagulation basins to these filters; second, of the water leaving the filters; and, third, of the filtered water after disinfection treatment. If the quality of the water applied to the filters is below the standard, obviously the succeeding processes will be called upon to perform more work than their reasonable share. This should be prevented by making such improvements or extensions in the processes preceding the filters as are necessary. In many instances it may be apparent that storage and plain sedimentation preceding coagulation will be necessary to produce the desired results.

In Ohio it is considered that the minimum necessary treatment of a water supply of surface origin demands coagulation, filtration and disinfection. It is not considered safe to depend upon storage, with watershed protection, even if the water is continuously treated for disinfection prior to delivery. In several instances in Ohio it has been attempted to provide satisfactory drinking water by the use of impounding and storage reservoirs in the development of surface water supplies, such reservoirs having holding capacities equivalent to one hundred days consumption or more. The results have been generally unsatisfactory and such water supplies have been objectionable at times, due to bacterial contamination and undesirable physical characteristics, the correction of which has demanded proper treatment by coagulation and filtration with disinfection as a final factor of safety. It should be stated that the topographical and geological conditions of Ohio and the nature of the industrial and agricultural development of the state generally do not favor the use of reservoirs except for purposes of securing an adequate water supply and providing the primary step in purification.

In no instance in Ohio has a municipality or water company attempted to control its water supply by purchasing the entire catchment area and the State Department of Health, recognizing the great expenditures required and the uncertainty of securing safety in this manner, has not encouraged such purchases. Reasonable protection and maintenance of watersheds can be secured without purchase under Ohio Laws and the saving of funds thus resulting is generally sufficient to pay the cost of constructing purification works.

The value of storage is recognized and in many instances it is employed as a preliminary step in purification, being followed by

processes of coagulation, filtration and disinfection. Storage is advantageous in this connection, not only as a step in purification but also as a means of equalizing the chemical and physical quality of the water for treatment. This equalization simplifies plant operation and results in more regular efficiencies.

RICHARD MESSER:[10] Colonel Johnson has set before the Association an ideal with regard to the standard for drinking water, which it is hoped will soon be accepted by the public generally. The wonderful accomplishments in the field of water purification during the short period of thirty years, which have resulted in such a remarkable reduction in rates of typhoid and other diseases recognized as being due to impure drinking water, seems almost unbelievable. What improvements and changes in methods will occur during the next thirty years nobody can predict, although one thing is certain, that the time is fast approaching when there will be few, if any, cases of typhoid or other intestinal diseases due to drinking water furnished for municipal use.

The writer is in full agreement with the stand taken by the author that there are few, if any, exceptions to the general rule that surface waters, no matter under what conditions they are collected, are potentially dangerous, and therefore should be artificially treated by the most up-to-date methods, before the water is turned into the distribution system. It is all very well to talk about patrolling a watershed, but in actual practice it is very difficult to prevent the pollution of the reservoir or tributary streams in some of the ways which have been mentioned in this paper. The writer has in mind two impounded supplies, the entire watersheds of which are owned by the cities and are under patrol. In these instances the most serious danger is from poachers who visit the reservoir at night or in the early hours of the morning. Consider for a moment a large reservoir originally stocked with game fish, in which fishing has been prohibited for a number of years. To a person who loves the sport, the temptation to take a chance, even though it means breaking rules and regulations and possible arrest, is often too great to resist. True, the number of watchmen might be increased but this means added expense, which in the opinion of the writer could to better advantage be put into the operation of a purification plant.

[10] Chief Engineer, Virginia State Board of Health, Richmond.

From time to time pathetic letters are received, petitioning the State Board of Health to lift the lid or grant special permits under certain rigid conditions. The writer recalls one argument presented to the effect that the city water had a "fishy odor," that this was due to the excessive number of fish in the reservoir, and calling upon the Board to permit the members of a certain club to assist the city in removing them. Needless to say copper sulphate was applied instead.

During the past years the government, through its Forest Service, has acquired large tracts of land to be held as reservations. When possible, the Service has selected areas from which public supplies are collected and in this way has helped materially in preventing pollution. However, if the reservations are to serve the purpose for which they are acquired, the trees will have to be cut and removed some day, with the possibility of dangerous contamination of the supply. Nevertheless the policy of the Forest Service in giving preference when possible to public water supply catchment areas, is to be encouraged. At the present time several of the smaller towns in Virginia collect their supplies from areas which are entirely owned by the government.

In the State of Virginia there are nine impounded supplies, serving cities of 10,000 and over. Of these, six are filtered and chlorinated and catchment areas of the other four are entirely owned by he municipality or private companies. It should be mentioned, however, that the filter plants were installed for other than sanitary reasons, those in eastern Virginia because the impounded waters are highly colored and are subject to algae troubles and those in the central and western part of the state because the waters are usually turbid, due to the red clay soil, and also subject to algae troubles. One of the cities has spent about $300,000 to filter a water taken from a catchment area of 39 square miles, almost half of which is owned by the city. The original plan was to purchase the entire area but afterwards it was decided that this was too expensive an undertaking and that filtration would be the wisest course. The other four places referred to will in all probability decide to resort to aeration and filtration before many years in order to secure a supply which is entirely satisfactory.

It is very interesting to note the change in sentiment on the part of the public during the past ten years in demanding water not only safe but with the best possible physical quality. We no longer have to

explain the advantages of such a supply because the thinking people take these things for granted. The only questions at issue are with regard to the financing of the work and the extra cost of operation.

One of the most difficult problems in connection with the state supervision of public supplies is the control of the medium size and small filtration plants. With the highly turbid water and with the aid of chlorine, fairly satisfactory results are obtained. Nevertheless, a small filter plant, no matter how carefully designed, will go wrong at times, due to carelessness and ignorance on the part of the attendant. For obvious reasons a town of 5000 or 6000 population, or smaller, cannot afford to employ a skilled operator, or at least the officials cannot see their way clear to do so. Although the writer is fully aware that any apparatus like a filter plant, requires fairly intelligent care and operation to function satisfactorily, nevertheless he ventures the suggestion that additional safeguards must be considered by the designer of these smaller plants, which will never receive the expert attention required for larger installations. How can the factor of safety be increased by the designer? Will longer periods of coagulation, finer sand and slower rates help in this? The writer believes that the peculiar requirements for a smaller installation must be given farther study with the view of making such a plant as nearly "fool proof" as possible, especially in view of the rapidly increasing number of these smaller plants which are being constructed each year as compared with the few larger installations. Most of the larger cities are already cared for and the smaller places are demanding equally good water.

JOHN M. DIVEN:[11] One of the unexpected sources of possible pollution of a stored water occurred in the writer's experience. The reservoir was a large one as compared with the amount of water drawn, and the movement of the water very slow. The outlet gate house was so located as to be a long distance from any inlet stream of appreciable volume. The water movement was thoroughly tested by means of floats so constructed as to catch the effect of any currents at varying depths. The ice movement was studied by means of beer kegs (if you know what is meant) painted in various colors and numbered, distributed at many points on the ice and closely watched when the ice broke up in the spring.

[11] Secretary, American Water Works Association, New York.

The movement of both water and ice towards the gate house was so slow that it seemed unlikely that it would flow or float from any probable source of pollution to the gate house within the life of any pathogenic bacteria. The water was considered a 'safe' and satisfactory supply and bacteriological analyses had always carried out this supposition. The typhoid rate in the city was very low.

Some trouble with a concrete spillway made it necessary to draw the water down about 5 feet during a cold winter. The ice, where cut back of the spillway, measured 26 inches in thickness. At the rather shallow outlet or mouth of one of the principal streams feeding the reservoir, the ice settled on the bottom the entire width of the stream and for a considerable length In the spring weather when the stream "broke up," the flow did not break up or lift the ice at their mouths, but the water ran over the heavy reservoir ice, which had not broken up. This spring flood water was naturally turbid, and from the stream entering the reservoir nearest to the gate house, a distance of about 1½ miles, the muddy water flowed over the ice directly to the gate house. Turbid water soon appeared in the city mains, something hitherto unknown from this source of supply. Immediately samples were taken for analysis, and a hurried visit to the reservoir revealed the cause. For though the warm water and increased flow had broken the ice at the mouth of the creek, and conditions were very quickly back to normal, the course of the muddy water over the ice could be clearly seen, a muddy fan-shaped streak. The water had made the journey, usually taking months, in a few minutes.

Fortunately there were very few sources of pollution on the stream, and the bacteriological examination showed coli absent. However, this might have been different, and, needless to say, dynamite was used at the mouth of the stream the next winter. The "phenomenon" of water putting on skates and racing to the gate house did not occur at the mouths of the other confluent streams owing to a different conformation of stream beds and banks. The incident, however, shows an added reason for not depending entirely on sedimentation for safety in a water supply.

C. A. EMERSON:[12] Each impounded supply that is rendered safe by some positive treatment not only protects the consumers of the district against water-borne disease, but serves as a missionary

[12] Chief Engineer, Pennsylvania State Department of Health, Harrisburg.

to the "conservative" owners or consumers of water supplies in neighboring municipalities which are not so protected.

Even in spite of all that has been said regarding the danger of using untreated surface supplies, how frequently in the case of the small waterworks taking a supply from a reservoir in a forest reserve or in waste mountain lands with but a few habitations and slightly travelled highways on the watershed, do we find every consumer is only too willing to swear "that we have the finest water in the world." Chlorination is mentioned as a necessary safeguard and factor of safety and to a man they "don't want dope put in that water," particularly as some public spirited citizen has spread the gospel that chlorine is the "same stuff the German used to poison our boys during the war."

Oftentimes, this reaction against chlorination is well founded and is based upon a vivid recollection of the taste in the water of some neighboring community. Too frequently, the proponents of this treatment feel their duty is well accomplished when the apparatus has been installed and payment received. They go their way with a sense of having benefited humanity and then in a deplorably large percentage of cases the local waterworks officials promptly overdose the supply. As soon as complaints begin to pour in the germicide is reduced to such an extent that its value is negligible. If every member of this Association having to do with a waterworks making use of chlorination would determine that in his particular plant the rate of application would be gauged by one of the simple tests for residual chlorine, made at least twice each day and the results checked by frequent bacteriologic examinations, much of the prejudice against this valuable method of treatment would disappear.

The adherents of longtime storage frequently make a grievous error, pointed out but not particulatly emphasized by the author, namely, failure to consider the variation from the nominal detention period in the reservoir which occurs during seasons of high stream flow, when the volume of water wasting over the spillway continuously for days or weeks, is many times the water consumption and also during a protracted drought when the reservoirs are nearly empty. In these cases the nominal detention may be reduced from a period of several months to only a few days, so short in fact, that even neglecting wind action or short circuiting due to other causes, the improvement in quality of the water gained by storage practically disappears.

The extension of improved highways and the phenomenal increase in number of motor vehicles have a material influence on impounded water supplies. A few years ago when Sunday and holiday picnics were limited to a horse and buggy trip of a few miles or a trolley ride to a well improved resort, many watersheds were rarely visited by the public, but now-a-days these same watersheds may be traversed by scores of people who are totally unaware that the small stream flowing through the attractive woodland reached by only a "short run" from the main highway is the water supply for a city and consequently take no thought to guard against pollution of the banks.

In Pennsylvania the value of chlorination as a further safeguard to the purity of impounded water supplies is fully realized as witnessed by over eighty-five installations on such supplies, but at the same time it is believed attention should continually be called to the shortcoming of chlorination, as for instance, when duplicate apparatus is not available, when the water is occasionally turbid or when the installations are so remotely situated that the apparatus receives only slight attention. The low cost of chlorine treatment appeals to all, but it must not be offered as a substitute for filtration unless a careful study by competent judges demonstrates that filtration is not required.

C. ARTHUR BROWN:[13] If a rigid interpretation is placed on some of the statements in Colonel Johnson's paper, the writer is only partially in harmony with his views. To attempt complete and adequate control of catchment areas, in the vast majority of cases, is obviously impractical. Even in cities where the catchment area is small enough to permit some sort of control, the expense is usually too great to make it attractive.

Regardless of expense, the efficiency of such control is dependent on the human equation. To depend on this is to take chances, and to violate the good old maxim: "It is better to be safe than sorry." To reduce the human equation to the minimum is merely sound engineering. Therefore, the writer is in accord with Colonel Johnson in believing it to be poor engineering to rely solely on the ownership or control of the watershed, regardless of expense or care taken to protect the supply.

To admit this, and most of the advocates of control will admit it, necessitates impounding reservoirs as an additional precaution.

[13] Sanitary Engineer, Lorain, Ohio.

If the reservoirs cannot be depended on to overcome entirely what the care of the catchment area fails to do, then the combined control of watershed and the use of impounding reservoirs must be deemed inadequate. Experience had shown the folly of attempting to obtain a pure supply by care of the catchment area without using impounding reservoirs. It has also shown the folly of relying on the impounding reservoirs alone. To make the combined use of the two ineffective, it is required only that the time periods of failure in each be made coincident. The writer is certainly in accord with Colonel Johnson in thinking it unwise to rely upon this lack of coincidence. If the supply is bad enough to require control of the catchment area and the use of impounding reservoirs, it is certainly bad enough to require filtration.

To go to great expense in attempting to own and control the catchment area and to build expensive impounding reservoirs is not, to our way of thinking, good engineering practice. It savors of putting the cart ahead of the horse. A properly designed filtration plant of adequate capacity will usually be found cheaper in the majority of cases. It is a more flexible and consistently reliable means of obtaining a pure water than either or both of the previous mentioned methods. It will usually be found cheaper to operate. It would be better first, to provide the filter plant, then, if necessary, to effect control of the catchment area and build such reservoirs as are found necessary.

Up to this point, the writer is in agreement with Colonel Johnson, but when he states that all supplies should be chlorinated all the time, the writer begs leave to differ. He does not believe that chlorine should be used all the time to chlorinate all filtered water, nor does he believe that any filtered water should be chlorinated all the time. On the contrary, he is of the opinion that no filtered water should ever be chlorinated except as an emergency measure or under such restrictions as to leave the treated water absolutely free from objectionable odors or tastes.

The use of chlorine in treatment of filtered water has done more to retard progress and destroy the morale of operators than any other single cause. It is now responsible for holding up more permanent betterments of public water supplies than all other causes put together.

It is bad enough to overdose a natural water with chlorine to a point where it is more than reminiscent of a dissecting room, but

to treat a filtered water with this nauseating gas to a point where the odor and taste of the filtered water is such as to render it so objectionable that the average user cannot drink it without gagging over each glassful, and where even tea and coffee made from the water smell so vilely and taste so disgustingly that even a white mule offers an acceptable contrast, may be deemed good practice by some overzealous sanitarians, but as far as the writer is concerned he personally would prefer a water of great palatability and less freedom from bacteria of doubtful pathogencity.

The use of this gas in such excess to produce these sickening odors and tastes may be necessary to render an unfiltered water sanitary. But if the efficiency of the process requires its use to the point of rendering a filtered supply as malodorous as many of those within the writer's knowledge, it is high time that we evolve a better practice.

A properly designed and operated mechanical filter does not require chlorine to produce results. If chlorine is required it is proof the filters are not being operated as they should and the obvious remedy is to bring the filters to the required degree of efficiency. The proponents of this method of rendering a water unfit for human consumption may argue that the average plant and operator of today are unable to produce such results. If this condition obtains it must be charged largely to the use of chlorine.

In dozens of plants operators have been heard to say there was no use in keeping the filters up to their maximum efficiency. They argue that when the filters fail to produce satisfactory results, it is unnecessary to bother about the filters. All that is required is to increase the amount of chlorine to be applied.

The public, justifiably, is very sensitive about the odor and taste of its drinking water. Most of the opposition to water purification systems of today is based on this objection of the public to vile odors and tastes in the purified water. If the taste and smell of a filtered water is so objectionable as to render it unsuited for human consumption, it is no more fit to be used than it would be if it were sweet and palatable and contained a few bacteria of doubtful origin. In fact, we should prefer the latter water.

In order to avoid the occasional use of water overtreated with chlorine to the point where it becomes seriously objectionable, some objectors have gone so far as to install equipment in their homes to render the water sweet and palatable. The expense of such equipment varies from $250 to $500 per family.

With these known facts staring us in the face, the writer feels justified in voicing a disagreement with Colonel Johnson in his statements about chlorination. Furthermore, he believes that we are standing in our own light when we, as engineers, permit such conditions to continue.

There are dozens of cities in the country where bond issues have failed because of the objection of the public to the odors and tastes of filtered supplies. Personally, the writer has a lot of sympathy with any objector who refuses to vote money to build plants to use chlorine to overtreat a water. If the filtered water is to taste and smell no better than the natural water, why build a filter plant?

The sooner the engineer sees he is destroying his own business by permitting this condition to continue, the better it will be for the engineer. The sooner the public learns that it is unnecessary to use chlorine to this point in a properly designed and operated filter plant, the sooner we may look for a better support by the public of the construction of such plants and the less opposition we will encounter to the permanent improvement and betterment of public water supply.

The interest of the public should be the interest of the engineer. If we, as engineers, do not conserve this interest, we are illogical in expecting the support of the public, and the writer contends that we, as engineers, should correct this erroneous belief and restrict the use of chlorine to the point where it will never be possible to produce an objectionable odor or taste in a filtered water.

In order to do this it is essential that the filters be maintained in the condition to produce water of the required degree of purity without resorting to the use of liquid chlorine. This is entirely feasible. If the plant be well designed and well operated, it can produce water of the required degree of purity. If it does not produce water of the required degree of purity, then the operator should be required to take such steps as will bring the plant up to the required degree of efficiency. There are relatively few plants where the rate of 125,000,000 gallons per acre is not exceeded consistently where this may not be done, and in plants where it can not be done the faults are fairly obvious to an experienced engineer, and the means for correcting such faults are well known and should be used.

Our sanitary authorities, State Boards of Health, consulting engineers and filter builders can bring about this change, if they unite in doing so. The writer is quite aware of the fact that his views will

meet strong opposition. He has hesitated for sometime in giving voice to them, but he is satisfied that there are many evils to be charged to the use of this noxious gas which can be corrected, and which we, as engineers, should take definite and positive steps to correct.

ROBERT B. MORSE:[11] It seems strange that it is still necessary to argue, before a technical body, points concerning which the evidence appears incontrovertible; to discuss the question that, because a thing has not occurred, it will not occur; to show that a chain is no stronger than its weakest link; to dally with the fact that the best of watershed control may not prevent pollution of a supply; to prove that the effective storage period in a reservoir cannot be measured by so simple an expression as the ratio of its full available capacity to the normal withdrawal from the reservoir; in short, to carry conviction everywhere that the best known methods of safeguarding our public water supplies should be employed without stint.

Apparently the necessity of discussing these matters before such an association as this, in the able manner that Colonel Johnson has, will continue at least as long as there is danger that engineers and sanitarians may be led not to adopt methods of water purification of comparatively recent development because, on the basis of past events, they may not seem to have been necessary in one section of the country.

Let our water supplies be "innocent." Lest, however, "repentance" overtake us, let them be innocent at the point of delivery as well as at the source; and if they cannot be kept innocent at both ends, let them assuredly be made innocent at the consumer's door.

There can be no quarrel with the school of sanitarians who "still cling to the idea that it is permissible to rely upon primary lines of defense against water-borne disease" and "offer vague arguments against water filtration and sterilization 'except where necessary.'" The case is stated exactly. Nobody would favor filtration and sterilization, or either one, except where necessary. But is the first of these methods of purification necessary only for making the physical quality of a water acceptable, or are one or both of them required as a sanitary measure only where waters are derived from

[11] Chief Engineer, Maryland State Department of Health, Baltimore; Chief Engineer, Washington Suburban Sanitary District, Washington.

inevitably polluted sources or are delivered without storage? In the writer's judgment, "where necessary" means in the great majority of places where supplies are taken from surface sources, even in sparsely settled regions, with the best regulated watershed control, even with long normal storage, and this in spite of a history of persistently low morbidity and in spite of any continued good analytical showing.

Maryland is not nearly as densely populated, on the average, as are some sections of the country; it cannot point to a long period of low prevalence of typhoid fever as supporting any policy of water treatment; but it is largely through strict adherence to the policy of purifying its surface water supplies that, within seven short years, the typhoid mortality in the whole state outside of Baltimore City has dropped from the forties to less than 9 per 100,000, and in this figure the strictly rural sections contribute mainly. Previous to 1914, with practically no state control over water supplies, no consistent progress had been made. In Baltimore, before the water was purified, the typhoid mortality rate was approximately the same as in the rest of the state, but now, after about a dozen years, it is four and a fraction.

The writer does believe it to be well worth while that over 97 per cent of Maryland's population, outside of Baltimore, served by surface water supplies, is using water that is either filtered, chlorinated, or filtered and chlorinated. If Baltimore is included, this figure rises to over 99 per cent. There are now only four small surface water supplies in the whole state that are not purified by one of these methods; in 1914 there were only five that were so purified.

The writer is not at all unmindful of the value of watershed patrol, watershed regulations and storage, as sanitary measures. He feels sure, however, that not many would advocate artificial storage reservoirs solely as a sanitary precaution, when surer and generally more economical measures are available.

Apparently, too little attention has been paid to the fact that storage is a relative term. Given an impounding reservoir, as generally constructed, the storage period may vary from time to time with atmospheric and other conditions. With varying winds and temperatures, short-circuiting currents, with flood run-offs perhaps a hundred or more times the volume of average inflow, with water level drawn down, with direct run-offs from ground surfaces near the reservoir outlet, how can it be figured that all the water at all

times receives the beneficent effect of long storage? How can one feel safe with so-called storage alone? When a storage reservoir can be constructed away from the stream from which it receives its supply, so that high run-offs cannot enter it, when it is of such shape and so arranged that its full displacement performs its function, when it is so protected that no direct surface wash can reach it, when it is of such size that all pathogenes in the entering water will die off before reaching the outlet, then, and then only, may one be assured of absolute safety in storage alone.

The sanitary value of storage in two Maryland reservoirs has been studied for the State Department of Health by two of the writer's assistants, Messrs. Wolman and Powell, for the purpose, in these cases, of investigating the results of subsequent purification by chlorination. One of these reservoirs was away from the stream from which it was supplied. It was found to comply essentially with the requirements of adequate storage except that it was not of sufficient capacity for its output. The other was an impounding reservoir formed by a dam built across the valley of the supplying stream, and subject therefore to high water conditions and direct surface wash. It was found, here, from a study of some eight months' duration, that the bacterial load on the liquid chlorine plant treating the effluent was extremely sensitive to lowered water levels, heavy rainfalls and rapid melting of heavy snow.

Reservoirs, either with short or long storage periods, by reason of their levelling influence, are valuable adjuncts to ease and economy of operation of subsequent purification works, but the writer believes it to be only rarely that they can be of such size, so arranged, and so guarded, as to compete economically, as a sanitary measure alone, with other methods of water purification. That confidence in the safety of rules and regulations for watershed control, and in ordinary storage, is misplaced, has been proven in the home of storage. It seems that the lesson that should have been learned from the sharp outbreak of intestinal disease at Peabody, Massachusetts, in 1913, was not learned at all, for we are told that the recommendation of the State Board of Health was that fishing in the reservoirs be prohibited and that the regulations established for the protection of the water supply be strictly enforced, not that the additional safeguard of further purification be applied to the stored water.